Beta Decay Correlations in Laser Trapped ^{21}Na

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A laser-trapped sample of radioactive atoms can be used as a source of beta activity for precise measurements of kinematic correlations to test predictions of the Standard Electroweak Model. The greatest advantage of such a source may be the ability to detect the low-energy recoil nuclei. ^{21}Na is produced on-line at the 88-Inch Cyclotron, and we collect up to 800,000 atoms in a magneto-optic trap (MOT).

We completed a measurement of the beta-neutrino correlation in ^{21}Na, finding a correlation coefficient $a_{\beta\nu}$= 0.5243(92), compared to the prediction based on the Standard Model of $a_{\beta\nu}$ = 0.5580(30).[1,2] Our measurement disagrees with the calculation by 3.6σ. None of the systematic errors examined so far explain the discrepancy. We also measured the final charge-state distribution of the daughter ^{21}Ne, finding agreement with an estimate based on the sudden approximation, and finding that a relatively large fraction of the ^{21}Ne are positively charged.[3]

Based on the favorable charge state distribution, we implemented a new detection scheme in the experiment. We detect the low-energy electrons shaken off by the daughter ^{21}Ne during the beta decay. All of the positively charged ^{21}Ne are produced by the emission of the outermost 3s electron, and these electrons are emitted isotropically with only a few eV. When accelerated to ~7 kV, the detection efficiency for these electrons in a second microchannel plate (MCP) is of order 1. During a recent run, the detection efficiency for a beta decay event (low energy electron in coincidence with a charged daughter ion) was roughly a factor of 15 higher than in the configuration using a β+ detector in coincidence with recoil ion detection (Fig. 1).

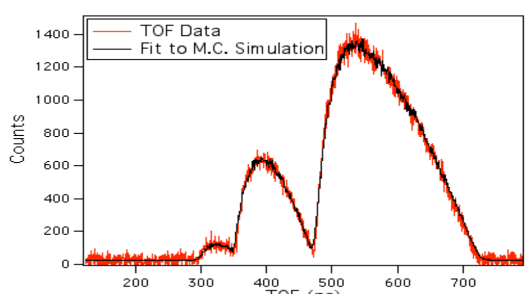

FIG. 1: Time-of-flight spectrum of ^{21}Ne ions coincident with shake-off electrons. Data are compared to a Monte-Carlo calculated TOF spectrum used to determine $a_{\beta\nu}$.

Without detecting the β+, we measure the unbiased momentum spectrum of the recoil ions, which is sensitive to the beta-decay correlations, **a**, **A**, **B**, and **D**, each of which can test for different types of new physics (Fig. 2).

Having added a second MCP to detect low-energy electrons, we detected ionized dimer molecules from a MOT containing stable ^{23}Na (Fig. 3) The dimers are formed in a photoassociation (PA) process in which two ground state atoms are resonantly excited by the trap lasers to an excited, attractive state of the molecule $^{23}Na_2^*$, which then decays to a cold, stable, ground molecular state. The molecules are detected via a similar PA autoionization process, in which two photons are absorbed, driving the molecule to an excited state which is fortuitously autoionizing. Only the MOT lasers are necessary. If the ^{21}Na undergoes beta decay while closely bound (~0.5 nm) to another atom, the momentum of the outgoing recoil ion can be perturbed if it scatters off of the hard interatomic potential (~ r $^{-12}$). Previous measurements of the beta-neutrino correlation were susceptible to this perturbation.[4] Our observed rate of dimer formation in ^{23}Na is consistent with cold PA studies in other alkali atoms, and with a level which would perturb $a_{\beta\nu}$ at a level of 5-6%. A measurement of $a_{\beta\nu}$ could be corrected by extrapolating to zero trap size with the improved statistics of our two-MCP detection scheme. Perturbation by cold molecules may be an extremely important limiting error source for proposed fundamental physics measurements using laser-trapped atoms.

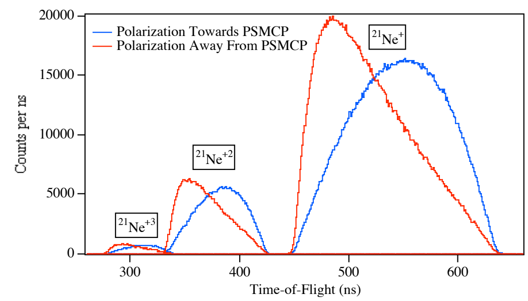

FIG. 2: Simulated TOF spectra with different lineshapes as a function of nuclear polarization.

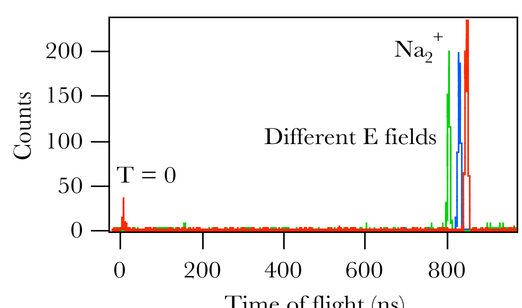

FIG. 3: TOF spectrum for $^{23}Na_2^+$ generated by the MOT lasers. Different E fields allowed identification as $^{23}Na_2^+$.

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